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Research Contributions of Nobel Laureate Francis H Arnold: A Study of Bibliometric Analysis

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Abstract

The study on 'Single Author' research analysis highlights the qualitative and quantitative aspects of research contributions made by Nobel Laureate Arnold FH in the field of chemical sciences for the directed evolution of enzymes. During her productive career 1980-2021, she has produced a count of 355 (273 journal articles) publications with 30644 citations were retrieved from Scopus database. The present study includes the analysis of research contributions made by Arnold FH with the bibliometric techniques and her role in the advancement of chemical science in the world. Her publications were distributed over 135 source titles which are having a good impact factor. She has collaborated with 496 authors which are resulted for 1444 authorships in which the most prolific collaborators are Bloom JD 15 publications, Snow CD 14 publications. Country-wise distribution of citations reveals that most of the citations are from the USA which accounts for 32919 of total citations. The papers end up with the opinion that Arnold contribution in the field of 'enzymes' which could help in to solve the humankind's chemical problems and study prove that she is an outstanding performer in the field of chemical sciences and source of information for budding scientists in the field of chemistry.

Keywords: Bibliometrics; Growth trend of Publications; Citations analysis; Co-authorship; h-index; Impact factor.

Introduction

Evaluation is a tool that helps in determining the quantity, quality, and value of something or someone; likewise, the bibliometric studies helps in determining the research productivity of individuals, institution, or a nation. Scientific publications seem to have provided the best available basis for measuring the output of individual scientists as their good correlation

between the eminence of scientist and their sustained research publications (Price 1986). (Kalyane & Kalyane, 1993) the term 'Scientometric Portrait' was came into picture in the paper 'Scientometric Portrait of Vinodini Reddy' authored by Kalyane and Kalyane.(Qayyum & Naseer, 2013) have explained the scientometric portrait which includes the mathematical and statistical techniques to analyse a pattern of the publication's, preferences, collaboration and chronological distribution of publications.

From the scientometric analysis, it is possible to develop to a model on the performance of a role model scientist of a country who has a direct bearing on the identification of promising scientist and human resource development in developing countries (Kademani, Kalyane & Kumar 2001). Individual scientists including the Nobel laureates have become the focus of scientometric studies for quite some time. Ever-growing stress has been laid on scientometrics to publish data on individual scientist rather than gross statistical "macro" data (Schubert &Glanzel 1992). Scientometric studies are highly valued by historians of science, biographers of scientist, science policy makers, administrators of scientific establishments, R&D mangers, documentalists, information scientists and journalists (Hazarika et al., 2010)

Literature Study

Considerable numbers of studies have been presented on individual scientist in various subject domains, in this section reviewed scientometric studies on Nobel Laureates in Science disciplines, they are: **(Gupta, 1983)**has conducted citation analysis study on S. Chandrashekar Nobel Laureate in physics, opines that high correlation in quantity, quality of works, citedness and receiving honours and awards, and opines that he has set up a very high standard for his followers to surpass it. **(Kademani et al., 1994)** have thrown light on scientific career of Noble Laureate in Physics C V Raman, studied the activeness in his research productions which, in which they have proved that C V Raman as a role model. **(Kalyane & Sen, 1996)** have evaluated 422 research outcomes of Pierre-Gilles de Gennes Nobel Prize winner in Physics with scientometric concepts of a productive career, in this study they have been applied Bradford's law of scattering to know the ratio of article scattered in journals. **(Kalyane & Kademani, 1997)** come with a scientometric study on Nobel Laureate in Physiology Barabara McClintock, in which they have focused on productive life of McClintock, more than 90% of papers follows solo authorship pattern. **(Kademani et al., 2001)** have tested with elements of scientometrics of 246 publications by Nobel Laureate in Chemistry Ahmed Hassan Zewail. Authors opine that awards and honours capable to grab the attention of fellow researchers in the field. **(Rushton, 2001)** has described Hans Eysenck's productivity in which evaluated for the influence of publications accounts for 748 citations. **(Kademani et al., 2002)** demonstrated

a detailed scientometric analysis of 192 publications of Harold Kroto Winner of Nobel Prize in Chemistry, in which they have provided in detail about the publication growth, dominant collaborator, core journals to publish his papers, dominant keywords used in the paper. **(Koganuramath et al., 2004)** studied the 115 research output of Nobel Laureate in Physics Ketterle are tested scientometrically to prove that he is role model for fellow researchers in Physics, suggested that 'Scientometric portrait' is appropriated phrase for studies on scientists and 'Informetric portrait' for the researchers in other disciplines. **(Kademani et al., 2006)** have presented the scientometric study on Noble Laureate in Chemistry Dorothy Crowfoot Hodgkin, in the publications examined with biobibliometric concepts. **(Sangam et al., 2006)** have explored the research pattern of G. N. Ramachandran, in which they elaborated on productive career output scattered in various field and has proven that he is the role model for the younger scientist in the field of chemistry. **(Sangam et al., 2006)** have brought scientometric portrait study on Prof. Peter John Wyllie which is an exploratory study includes the citations, authorship details, source titles used for communication, authorship credits etc. **(Akakandelwa, 2008)** has carried out to portrait the life sketch of Processor Seter Siziya concentrating on emphasis on his research contribution in medicine, findings of the study have indicated that professor Siziya has a brilliant and outstanding academic and research career. **(Lancaster et al., 1992)** have carried out the bibliometric analysis of the citations obtained by Ranganathan, the study includes the evaluation of parameter of bibliometrics, and the author shows that Ranganathan has outstanding performer in the field. **(González-Alcaide, 2014)** has tried to identify the bibliometric references to the papers published by Santiago Garisolia. Authors opine that the pattern set by Santiago may be followed by young scientists to achieve scientific excellence. **(Balutagi et al., 2020)** have measured the research contributions of Prof. Anurag Kumar and authors opine the scientometric portrait studies will be the source of inspiration and productivity for young professionals in the particular field. **(Varaprasad et al., 2010)** have illustrated the quantitative growth and development of chemical research by J. S. Yadav for the period form 1986-2009. The study indicates the Yadav's publication productivity and nature of the research activities were such that he is eminently qualified to be taken as a role model for younger generations to emulate. **(Kavitha & Chandrashekar, 2020)** have presented study which explored attributes of research publications of Prof K Byrappa, and they have proven Prof K Byrappa is an outstanding performer in the field; through analysis basic attributes of scientometrics.

Brief Bio-Sketch of Arnold FH

Frances Arnold was an American Chemical engineer who was born on 25th July 1956, Pittsburgh a city located America. She is proudly daughter of Josephine Inman and William Howard Arnold a nuclear physicist in America. She grew up in Pittsburgh suburb Edgewood, at present; she is working as Linus Pauling Professor of Chemical Engineering, at the Bioengineering and Biochemistry at the California Institute of Technology. In the year 2018, she has been awarded Noble Prize with George P Smith and Sir Gregory Winter for the use of directed evolution to engineering enzymes. Energy technology discipline was the interested area of Arnold and formed a company in 2005 to produce renewable fuels. Arnold decided to use a different approach, that of evaluation. She has been revised the old technique into new once which helps enzymes to work in the dimethylformamide, and she introduced her mutated enzymes into the environment that contained DMF and casein, and selected the new enzyme that was best at breaking down casein in DMF and introduced random mutations into that enzyme. She has succeeded to find the solution for modified subtilisin E, which is much better to destroy DMF.

Another significant example of the capabilities of Arnold's technologies is her creation of an outsized set of latest cytochrome P450 enzymes. The flexible structure of these enzymes gives them a wide range of functions in nature; in humans, cytochrome P450 enzymes are involved in the metabolism of harmonies, vitamins, and toxins. Using directed evolution, Arnold has repose on this versatile backbone to created novel catalysts that perform transformations unknown within the biological world, but important for a spread of chemical and pharmaceutical purposes. In addition to those applications, Arnold's work gives the scientist a fundamentals understanding of how proteins evolve and performance in nature.

Objectives of the Study

- The bibliometric study is assess the publications produced by Nobel Laureate Arnold FH based on publications indexed in the Scopus database;
- Chronological growth trend in publications; and most prolific research collaborators
- To get the information on solo and single authored publications;
- Most relevant source titles with impact factor;
- To know countries cited Arnold's work; and most frequent words used in the publications, and to get insights on citations pattern of Arnold FH.

Methods and Tools

The publication data for the bibliometric study on Arnold FH was sourced from the Scopus citations database (https://www.scopus.com/home.uri). Using search string ORCID (0000-000-3-0589) on 7th January 2021. As a result, a total of 355 documents were retrieved as the output by the author Arnold and on all of the retrieved documents were used as the base data for further analysis. VOSviewer software 2021 was used to develop Co-occurrences of author keywords, terms of papers published by Arnold FH and Co-authorship networks of authors and countries that distributed within a similar time span. Used Biblioshiny; an open-source tool for quantitative research in scientometrics and that include all the main bibliometric methods of analysis for generation of visualised images (*Bibliometrix R Package*, 2021).

Results of the Study

Growth Pattern of Publications by Arnold FH:

Innovation in research leads to growth in the publications, as observed from the Scopus citations database, Arnold has been published 355 research articles with 33993 citations in various domains were briefed in **Table-1**. Her first paper was published in 1980 was co-authored with one co-author Collier R K. her research activity peaked in the year 2014 in which she has published 20 articles with Mean total citation per article is 46, and mean total citation per year of 6.57, was followed by 2018 with 16 articles obtained a considerable number of citations in 3 years, which has shown the impact of publications on society and co-scientists in the field of chemical sciences.

Table-1: Chronological Growth pattern of Publications by Arnold FH

Sl. No.	Year	TP	Mean TC per Art	Mean TC perYear	Citable Years
1	1980	3	1.00	0.02	41
2	1981	0	0.00	0.00	0
3	1982	1	37.00	0.95	39
4	1983	0	0.00	0.00	0
5	1984	2	1.00	0.03	37
6	1985	4	78.00	2.17	36
7	1986	2	81.00	2.31	35
8	1987	1	57.00	1.68	34
9	1988	2	27.50	0.83	33
10	1989	2	34.50	1.08	32
11	1990	4	71.25	2.30	31
12	1991	11	116.54	3.88	30
13	1992	5	43.40	1.50	29
14	1993	7	72.570	2.59	28
15	1994	5	75.80	2.81	27
16	1995	8	84.25	3.24	26

17	1996	11	93.00	3.72	25
18	1997	13	89.07	3.71	24
19	1998	8	198.5	8.63	23
20	1999	14	178.14	8.10	22
21	2000	12	105.83	5.04	21
22	2001	14	230.57	11.53	20
23	2002	12	154.50	8.13	19
24	2003	13	90.46	5.03	18
25	2004	12	98.75	5.81	17
26	2005	14	207.21	12.95	16
27	2006	14	115.783	7.72	15
28	2007	12	73.33	5.24	14
29	2008	5	199.00	15.31	13
30	2009	15	121.60	10.13	12
31	2010	7	55.42	5.04	11
32	2011	14	72.71	7.27	10
33	2012	9	30.00	3.33	9
34	2013	14	86.350	10.79	8
35	2014	20	46.00	6.57	7
36	2015	13	54.460	9.08	6
37	2016	12	50.83	10.17	5
38	2017	12	63.16	15.79	4
39	2018	16	42.37	14.13	3
40	2019	6	30.83	15.42	2
41	2020	5	2.00	2.00	1
42	2021	1	0.00	0.00	0
Total		**355**			
TP= Total Publications					

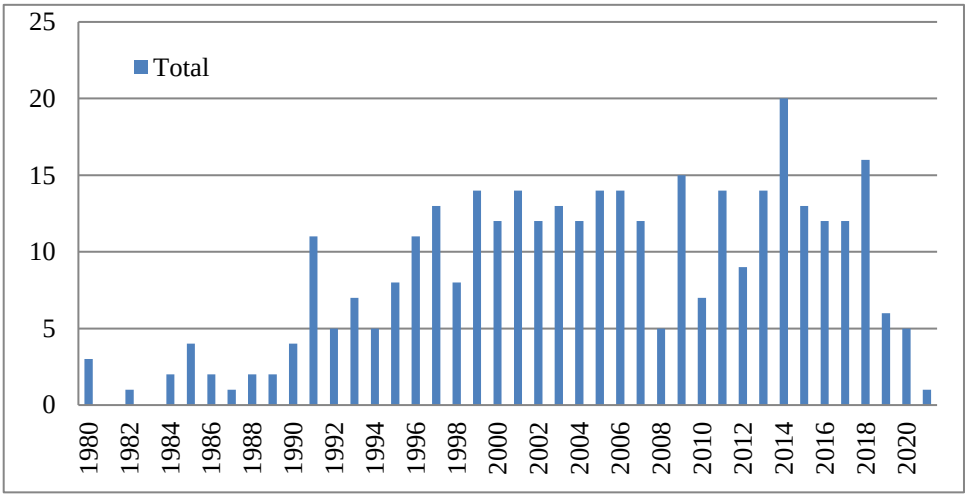

Figure-1: Growth pattern in publications of Arnold FH

Prolific Collaborators of Arnold FH:

Arnold has produced 355 research publications with 496 collaborators which was resulted in 1444 authorship, in which Arnold has been shared the 355/1444 (24.58 %) of authorship with article fraction of 115.72; while remaining co-authors all together shared 75.41% of

authorships. It was observed that 449 authors are produced around 1-5 papers each, 40 authors published 6-10 articles each, 6 authors published 11-16 articles each. The research productivity of top 25 predominant authors varies from 7 to 15 articles each. Fifteen publications of Bloom with article fraction of 3.73 have made him a most prolific collaborator of Arnold, was followed by Snow CD with 14 publications with article fraction of 2.16, Brinkmann-Chen S 13 publications. The co-authorship network showed in Figure 2, which will provide to trace the eminent scholars in the field of chemical sciences are shown in **Table-2.**

Table-2: Prolific Collaborators of Arnold FH

SL. No.	Authors	NA	AF
1	Arnold FH	342	115.72
2	Bloom JD	15	3.73
3	Snow CD	14	2.16
4	Brinkmann-Chen S	13	2.62
5	Buller Ar	13	2.55
6	Chen K	13	3.19
7	Meinhold P	12	2.22
8	Cahn JKB	10	1.97
9	McintoshJA	10	1.87
10	Romero PA	10	2.81
11	Bedbrook CN	9	1.71
12	Arnold F	8	1.92
13	Blanch HW	8	2.50
14	Collins Ch	8	2.02
15	Otey CR	8	1.42
16	Renata H	8	1.50
17	Smith MA	8	2.13
18	Wang ZJ	8	1.63
19	Zhao H	8	2.98
20	Brustad EM	7	1.44
21	Cirino PC	7	2.36
22	Coelho PS	7	1.70
23	Drummond DA	7	1.40
24	Farwell CC	7	1.44
25	Johnson RD	7	2.67
Total of 1-25		567	
Total of other 471 authors		877	
Total		**1444**	
NA=Number of Authorship, AF= Articles Fractionalized			

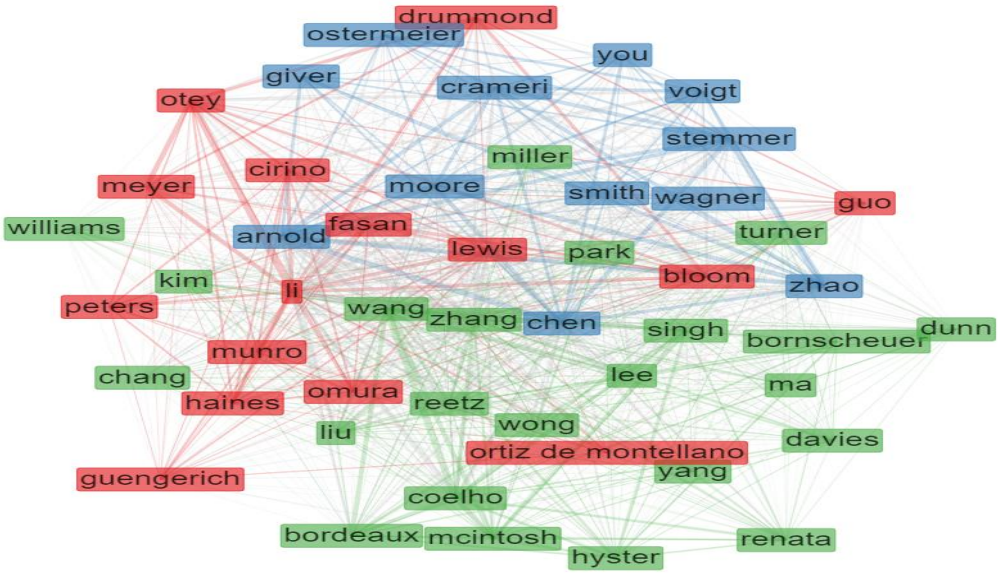

Figure-2: Authors collaborative network of Arnold FH

Authorship pattern of Arnold FH:

"Multiple authorship is a well-recognized feature of modern science and there has been a consistent trend towards increased collaboration in all branches of science during the present century" (Karisiddappa et al.1990). Publications under various authorships have been shown in **Table-3** which shows the single and multi-authored publications; from which it can be noticed that out of 355 publications, 333 have resulted in multi-authorship, while only 22 publications have resulted with solo authorship, can found mega collaborated publications; one paper written in collaboration of 20 authors and another paper is in collaboration of 16 authors; three authored publications shares 21.40% of total publications, was followed by two authored publications which account for 74. Thus, it brings clarity in the increasing trend towards collaborative research in the field of chemical sciences.

Table-3: Authorship pattern of Arnold FH

BA	Year	Publications under various authorships										Multi-Authored	TP	TC	PCA
		1	2	3	4	5	6	7	8	9	>=10				
24	1980		2	1								3	3	3	1
25	1982			1								1	1	37	2
26	1984			1			1					2	2	2	3
27	1985			3			1					4	4	312	4
28	1986		1	1								2	2	162	5
29	1987				1							1	1	57	6
30	1988	2										0	2	55	7
31	1989		1	1								2	2	69	8
32	1990	1	2	1								3	4	285	9
33	1991	1	5	1	1	2	1					10	11	1282	10
34	1992	1	1	1		2						4	5	217	11

35	1993	3	1	1	1	1						4	7	508	12
36	1994		1	3	1							5	5	379	13
37	1995		4	1	3							8	8	674	14
38	1996	1	4	3	1	1			1			10	11	1023	15
39	1997	1	6	2	2	1	1					12	13	1158	16
40	1998	3	1	1	2	1						5	8	1588	17
41	1999		5	3	2	2	1				1	14	14	2494	18
42	2000	1	3	5	1	1	1					11	12	1270	19
43	2001	1	1	3	7	2						13	14	3228	20
44	2002		4	5		3						12	12	1854	21
45	2003		4	1	3	2	2	1				13	13	1176	22
46	2004		1	5	3	1	1	1				12	12	1185	23
47	2005		1	2	1	7	2		1			14	14	2901	24
48	2006	2	1	4	3	2	2					12	14	1621	25
49	2007		3	1	3	2	3					12	12	880	26
50	2008		1	2		1			1			5	5	995	27
51	2009	1	6	2	1		1		1	1	2	14	15	1824	28
52	2010		2			2		1	1		1	7	7	388	29
53	2011	1	3	2	2	3	2		1			13	14	1018	30
54	2012		2	1	1	1		1	1	1	1	9	9	270	31
55	2013		1	4	4	1		3		1		14	14	1209	32
56	2014		3	4	2	4	5			1	1	20	20	920	33
57	2015	1	2	2	1	2	1	1	1	2		12	13	708	34
58	2016				3	2	2	1		1	3	12	12	610	35
59	2017			3	2	3	2		1		1	12	12	758	36
60	2018	2		2	3	4	4	1				14	16	678	37
61	2019			1		1	2	2				6	6	185	38
62	2020		1	2			2					5	5	10	39
63	2021		1									1	1	0	40
Total		**22**	**74**	**76**	**54**	**54**	**37**	**12**	**9**	**7**	**10**	**333**	**355**	**33993**	
BA= Biological Age, TP= Total Publications, TC= Total Citations, PCA= Productive Career Age															

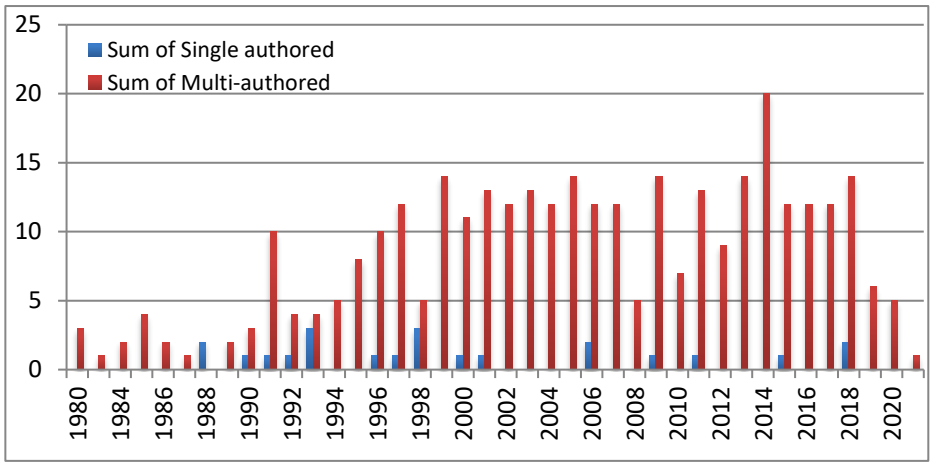

Figure-3: Authorship pattern of Arnold FH

Chronological distribution of citations:

A number of citations may represent the quality of work done by an individual scientist. Data presented in **Table-4** replicates that the range of references per articles. During the study period, Arnold has been responsible for to publish 355 papers in which 11 (4.22%) articles remained uncited till now. Of total publications 155 publications obtain citations ranged between 1-50 which was then considered the largest group in ranges; was followed by 82 publications receives citations ranged between 51-100. Two publications in a range of 351-400 are to be considered as a low group ranging, which clearly indicates that the quality publications may attract the more number of citations.

Table-4: Study of Citations obtained by Arnold FH

Year	0	1-50	51-100	101-150	151-200	201-250	251-300	301-350	351-400	>=401	TP
1980	2	1									3
1981											0
1982		1									1
1983											0
1984	1	1									2
1985		2		1	1						4
1986		2									2
1987			1								1
1988		1	1								2
1989		1	1								2
1990		1	2	1							4
1991		3	4	2	1					1	11
1992		4			1						5
1993	2	3	1					1			7
1994		1	2	2							5
1995		2	3	3							8
1996		5	4			1		1			11
1997	1	3	4	3	1		1				13
1998		4	1						2	1	8
1999		4	2	2	2	1	1	1		1	14
2000		5	1	3		1	2				12
2001		4	2	3	1	1	1	1		1	14
2002		2	6				1	2		1	12
2003		5	3	2	1	1	1				13
2004		4	6		1					1	12
2005	1	3	1	3	1	1	1			3	14
2006	1	4	2	6						1	14
2007	1	4	3	2	2						12
2008		2		1				1		1	5
2009		5	5	1		2	1			1	15
2010		2	4	1							7
2011	1	7	2		3	1					14
2012		8	1								9
2013		6	4	1	2					1	14
2014		12	5	3							20

2015		9	3				1				13
2016		9	2			1					12
2017		5	4	2	1						12
2018	2	12	1				1				16
2019		5	1								6
2020	2	3									5
2021	1										1
	15	**155**	**82**	**42**	**18**	**10**	**11**	**7**	**2**	**13**	**355**
TP= Total Publications											

Highly cited Publications of Arnold FH:

In **Table-5** information on top twenty, highly cited publications of Arnold has been provided with their citations received. We have compared the citations in two databases i.e. Google Scholar Citations (GSC) and Scopus database (SC), comparison of citations in both databases is quite interesting; the total of citations of top 20 highly cited publications is 15874 citations in GSC and 10561 in SC citations. The top article receives a sum of 2266 citations in GSC while in SC it is 1529 with total citation per year accounts for 72.81; the impact factor source title is 8.385 was published in the Journal of Physical Review Letters. She has published a journal article with a high impact factor of 55.47 in the year 2001. Citations analysis in one the important tool to evaluate the impact of publications produced by an individual, the single citation is also important for the author; it may not give a comprehensive insight on citations if rely on the single database; comparison may give a clear picture in citations analysis and these articles are considered as top 20 highly cited publications of Arnold FH. This inspires to fellow and upcoming scientist in the field to work in collaboration and to get cited.

Table-5: Highly cited publications of Arnold FH

Sl. No.	Paper	GSC	SC	TCPY	IFST
1	Thorsen, T., Roberts, R. W., Arnold, F. H., & Quake, S. R. (2001). Dynamic Pattern Formation in a Vesicle-Generating Microfluidic Device. Phys. Rev. Lett., 86(18), 4163–4166. https://doi.org/10.1103/PhysRevLett.86.4163	2266	1529	72.81	8.385
2	Fu, A. Y., Spence, C., Scherer, A., Arnold, F. H., & Quake, S. R. (1999). A microfabricated fluorescence-activated cell sorter. Nature Biotechnology, 17(11), 1109–1111. https://doi.org/10.1038/15095	1322	811	35.26	36.558
3	Basu, S., Gerchman, Y., Collins, C. H., Arnold, F. H., & Weiss, R. (2005). A synthetic multicellular system for programmed pattern formation. Nature, 434(7037), 1130–1134. https://doi.org/10.1038/nature03461	1188	748	44	24.36
4	Bloom, J. D., Labthavikul, S. T., Otey, C. R., & Arnold, F. H. (2006). Protein stability promotes evolvability. Proceedings of the National Academy of Sciences, 103(15), 5869–5874. https://doi.org/10.1073/pnas.0510098103	991	684	42.75	9.412
5	Zhao, H., Giver, L., Shao, Z., Affholter, J. A., & Arnold, F. H. (1998) Molecular evolution by staggered extension process (StEP) in vitro	1125	545	22.71	36.558

	recombination. Nature Biotechnology, 16(3), 258–261. https://doi.org/10.1038/nbt0398-258				
6	Drummond, D. A., Bloom, J. D., Adami, C., Wilke, C. O., & Arnold, F. H. (2005). Why highly expressed proteins evolve slowly. Proceedings of the National Academy of Sciences of the United States of America, 102(40), 14338–14343. https://doi.org/10.1073/pnas.0504070102	737	528	31.06	9.412
7	Romero, P. A., & Arnold, F. H. (2009). Exploring protein fitness landscapes by directed evolution. Nature Reviews. Molecular Cell Biology, 10(12), 866–876. https://doi.org/10.1038/nrm2805	512	512	39.38	55.47
8	Brenner, K., You, L., & Arnold, F. H. (2008). Engineering microbial consortia: A new frontier in synthetic biology. Trends in Biotechnology, 26(9), 483–489. https://doi.org/10.1016/j.tibtech.2008.05.004	722	502	35.86	11.41
9	You, L., Cox, R. S., Weiss, R., & Arnold, F. H. (2004). Programmed population control by cell-cell communication and regulated killing. Nature, 428(6985), 868–871. https://doi.org/10.1038/nature02491	762	475	26.39	24.36
10	Fu, A. Y., Chou, H.-P., Spence, C., Arnold, F. H., & Quake, S. R. (2002). An Integrated Microfabricated Cell Sorter. Analytical Chemistry, 74(11), 2451–2457. https://doi.org/10.1021/ac0255330	739	462	23.1	6.785
11	Arnold, F. H. (1991). Metal-affinity separations: A new dimension in protein processing. Bio/Technology (Nature Publishing Company), 9(2), 151–156. https://doi.org/10.1038/nbt0291-151	615	455	14.68	36.558
12	Balagaddé, F. K., You, L., Hansen, C. L., Arnold, F. H., & Quake, S. R. (2005). Long-Term Monitoring of Bacteria Undergoing Programmed Population Control in a Microchemostat. Science, 309(5731), 137–140. https://doi.org/10.1126/science.1109173	690	446	26.24	20.57
13	Coelho, P. S., Brustad, E. M., Kannan, A., & Arnold, F. H. (2013). Olefin cyclopropanation via carbene transfer catalyzed by engineered cytochrome P450 enzymes. Science (New York, N.Y.), 339(6117), 307–310. https://doi.org/10.1126/science.1231434	539	410	45.56	20.57
14	Giver, L., Gershenson, A., Freskgard, P.-O., & Arnold, F. H. (1998). Directed evolution of a thermostable esterase. Proceedings of the National Academy of Sciences, 95(22), 12809–12813. https://doi.org/10.1073/pnas.95.22.12809	394	394	16.42	9.412
15	Arnold, F. H. (1998). Design by Directed Evolution. Accounts of Chemical Research, 31(3), 125–131. https://doi.org/10.1021/ar960017f	751	393	16.38	20.832
16	Chen, K., & Arnold, F. H. (1993). Tuning the activity of an enzyme for unusual environments: Sequential random mutagenesis of subtilisin E for catalysis in dimethylformamide. Proceedings of the National Academy of Sciences, 90(12), 5618–5622. https://doi.org/10.1073/pnas.90.12.5618	401	344	11.86	9.412
17	Joo, H., Lin, Z., & Arnold, F. H. (1999). Laboratory evolution of peroxide-mediated cytochrome P450 hydroxylation. Nature, 399(6737), 670–673. https://doi.org/10.1038/21395	421	341	14.83	24.36
18	Moore, J. C., & Arnold, F. H. (1996). Directed evolution of a para-nitrobenzylesterase for aqueous-organic solvents. *Nature Biotechnology*, *14*(4), 458–467.	601	334	12.85	36.558
19	Arnold, F. (2001). Combinatorial and Computational Challenges for Biocatalyst Design. Nature, 409, 253–257.	599	325	15.48	24.36

	https://doi.org/10.1038/35051731				
20	Yokobayashi, Y., Weiss, R., & Arnold, F. H. (2002). Directed evolution of a genetic circuit. Proceedings of the National Academy of Sciences, 99(26), 16587–16591. https://doi.org/10.1073/pnas.252535999	499	323	16.15	9.412
Total of 1-20		**15874**	**10561**		
GSC= Google Scholar Citations, SC= Scopus Citations, TCPY= Total Citation Per Year, IFST= Impact Factor of Source Title					

Channel-wise Distribution of Citations:

(Mamdapur et al., 2014) in their study, they have tried to trace out the channel-wise distribution of citations over a period of time. **Table-6** explores the year-wise distribution of citations over various types of documents used by Arnold. Out of the cited references, due to heavy use of journals the citation share of Journal articles is alone more than 83 % of total citations receives, was followed by reviews which ware accounts for 15.39%. It is observed by various studies on scientometrics that the journal articles are the most common channel of communications for their publications. Conference papers with 0.89%. There are 0.25% citations for Note; Short Surveys obtained 0.16% of citations, Book chapters and Editorial with 0.11% citations each respectively, which clearly shows that the channels used for communication are also matters in the gathering of citations.

Table-6: Form-wise distribution of citations

Year	Journal articles	Books	Book Chapter	Conf. paper	Editorial	Erratum	Letter	Note	Review	Short Survey	TC	%
1980				3							3	0.01
1981											0	0.00
1982	37										37	0.11
1983											0	0.00
1984				2							2	0.01
1985	299	13									312	0.92
1986	162										162	0.48
1987	57										57	0.17
1988	55										55	0.16
1989	69										69	0.20
1990	162								123		285	0.84
1991	1088								194		1282	3.79
1992	214				3						217	0.64
1993	416				28				64		508	1.50
1994	318								61		379	1.12
1995	598								76		674	1.99
1996	1016			7							1023	3.02
1997	816			6					336		1158	3.42
1998	1544							44			1588	4.69
1999	2320			169						5	2494	7.37
2000	1107				2				161		1270	3.75
2001	2225			34					969		3228	9.54
2002	1757								97		1854	5.48
2003	1157				5	14					1176	3.48

2004	1185										1185	3.50
2005	2485			0					259		2744	8.11
2006	1595					4				22	1621	4.79
2007	712			0		2			136	30	880	2.60
2008	483		10						502		995	2.94
2009	612		1	72			3	36	1100		1824	5.39
2010	383								5		388	1.15
2011	643		4	0					371		1018	3.01
2012	270										270	0.80
2013	1175		16						18		1209	3.57
2014	812		3	12		1		5	87		920	2.72
2015	340								368		708	2.09
2016	610										610	1.80
2017	559		2						197		758	2.24
2018	601		2			0			75	0	678	2.00
2019	150								35		185	0.55
2020	9								0		9	0.03
2021									0		0	0
Total	**28041**	**13**	**38**	**305**	**38**	**21**	**3**	**85**	**5234**	**57**	**33993**	**100**
TC= Total Citations												

Most Relevant Source Titles of Publications of Arnold FH

Selection of journals for publications is one of the important tasks for each and every researcher; journals are the most commonly used channels of communication, researcher keep on checking the journals about updated information regarding their particular field. Arnold has selected the high impact 136 source titles to communicate his publications; the top 25 journal have been provided with citations in **Table-7**, about 120 journals published 1-5 papers each, 8 journals published 6-10 papers each, 7 journals published 11-23 papers each during the study period. In Table 7 provided the list of most relevant sources titles of publications by Arnold. The top 25 highly used journals for publications accounted for 60% share of total publications, among these journals 'Proceedings of The National Academy of Sciences of The United States of America' is considered one of the heavily used source title for publications of Arnold, was followed by 'Journal of The American Chemical Society' with 21 publications. Arnold's H-Index accounts for108. These 135 journals used by Arnold for her publications may be considered as core journals in the field.

Table-7: Most relevant source titles of Publications

Sl. No.	Source Title	TP	%	IF	TC	%
1	Proceedings of The National Academy of Sciences of The United States of America	23	6.48	9.412	4206	12.37
2	Journal of The American Chemical Society	21	5.92	14.612	1446	4.25
3	Nature Biotechnology	18	5.07	36.558	3776	11.11
4	AngewandteChemie - International Edition	11	3.10	12.959	1259	3.70
5	Biotechnology And Bioengineering	11	3.10	4.002	670	1.97
6	Current Opinion In Biotechnology	11	3.10	8.288	946	2.78
7	Protein Engineering Design And Selection	11	3.10	1.774	477	1.40
8	Journal Of Molecular Biology	10	2.82	4.760	943	2.77
9	Applied And Environmental Microbiology	8	2.25	4.016	499	1.47
10	Current Opinion In Chemical Biology	8	2.25	9.689	961	2.83
11	Journal of Chromatography A	8	2.25	4.049	643	1.89
12	Chembiochem	7	1.97	2.576	391	1.15
13	Nature	7	1.97	24.360	2076	6.11
14	Science	7	1.97	20.570	1509	4.44
15	Trends In Biotechnology	6	1.69	11.410	1079	3.17
16	ACS Catalysis	5	1.41	12.160	93	0.27
17	Chemistry And Biology	5	1.41	-	296	0.87
18	Current Opinion In Structural Biology	5	1.41	6.908	510	1.50
19	Journal of Biomolecular Screening	5	1.41	2.370	209	0.61
20	Methods In Enzymology	5	1.41	1.394	92	0.27
21	Methods In Molecular Biology	5	1.41	10.710	16	0.05
22	Advanced Synthesis And Catalysis	4	1.13	5.451	295	0.87
23	Annals of the New York Academy of Science	4	1.13	4.728	33	0.10
24	Metabolic Engineering	4	1.13	7.263	268	0.79
25	Protein Engineering	4	1.13	1.774	646	1.90
Total of 1-25 journals		209			23339	**100**
Total of remaining 109 journals		146			10654	
Total		**355**			**33993**	
IF= Impact Factor, TC= Total Citations						

Counties that cited Arnold's publications

Acknowledgement to any works gives a work satisfaction to the creator of particular work; likewise in citations for the publications will inspire researcher to work hard and to contribute something to the society. **Table-8** provides the list of countries that are cited by Arnold's publications more. It is observed from the table that the USA with more than 96% of citations considered as one of the countries which cite Arnold's publications more, followed by Australia with 293 citations, France 200 citations, United Kingdom 250 citations, Switzerland 80, Austria 72, Germany 10, Canada 5 and Mexico 4 citations each. These countries may consider as most prolific countries to cite publications of Arnold. Co-authorship links with other organization have been provided in Figure 5.

Table-8: Prolific Countries cited Arnold's Publications

Sl.No	Country	TC	%	Average Article Citations
1	USA	32919	96.84	110.6
2	Australia	393	1.16	71.5
3	France	200	0.59	49
4	United Kingdom	250	0.74	91
5	Switzerland	80	0.21	52
6	Austria	72	0.24	50
7	Germany	10	0.03	10
8	Canada	5	0.01	5
9	Mexico	4	0.01	4
Total		**33993**	**100**	**100**
TC= Total Citations				

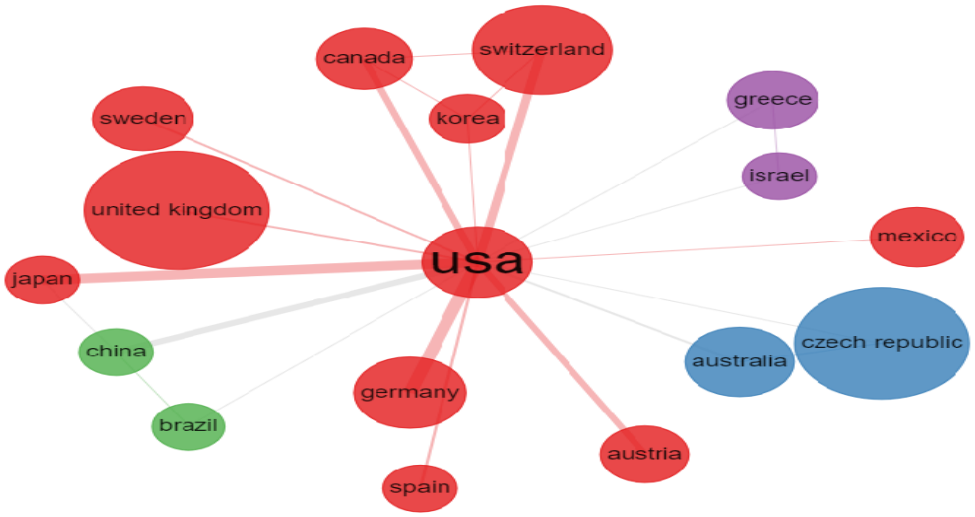

Figure-4: Most productive Countries

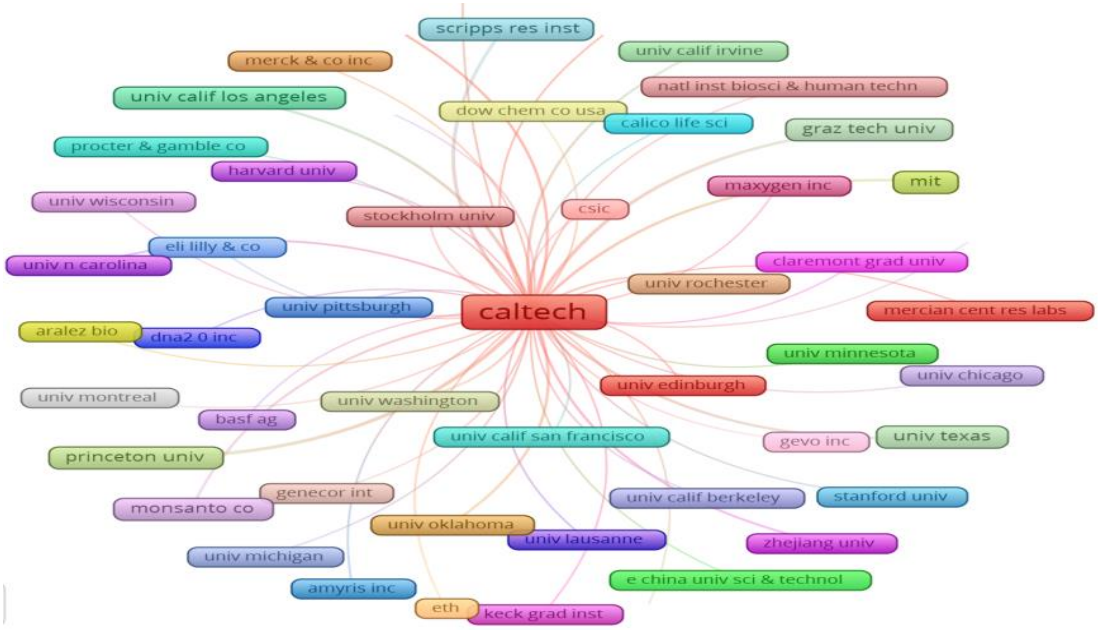

Figure-5: Co-authorship links with other organizations

Words used for frequently in the publications of Arnold FH

To know about the idea/theme of a researcher; keywords in the publications are more suitable to decide the same. Words used the most in the publications of Arnold have been illustrated in **Table-9** the top 30 words have been considered which are occurred for least 3 times. In which 'directed evolution' used for 48 times, 'directed evolution' for 28 times, 'biocatalysis' for 25 times, 'cytochrome p450' for 17 times, 'random mutagenesis' for 11 times. The co-occurrence of the network of the words has been given in Table 9 and Figure 6. Use of keywords in publications reflects the deep understanding of the subject by the researcher and these words are quite useful for construction of index and helpful in preparing thesaurus in the field.

Table-9: Most frequent words used in publications by Arnold FH

Sl. No.	Name of Word	Occurrences	Sl. No.	Name of Word	Occurrence
1	directed evolution	48	16	enzyme engineering	5
2	directed evolution	28	17	schema	5
3	biocatalysis	25	18	alkanes	4
4	cytochrome p450	17	19	amino acids	4
5	random mutagenesis	11	20	chimera	4
6	recombination	9	21	cyclopropanation	4
7	cellulase	8	22	cytochrome p450 bm3	4
8	enzyme catalysis	8	23	homologous recombination	4
9	enzymes	8	24	in vitro evolution	4
10	thermostability	8	25	metabolic engineering	4
11	subtilisin	6	26	molecular evolution	4
12	synthetic biology	6	27	mutagenesis	4
13	biofuel	5	28	protein design	4
14	chimeragenesis	5	29	protein stability	4
15	cytochromes	5	30	active learning	3

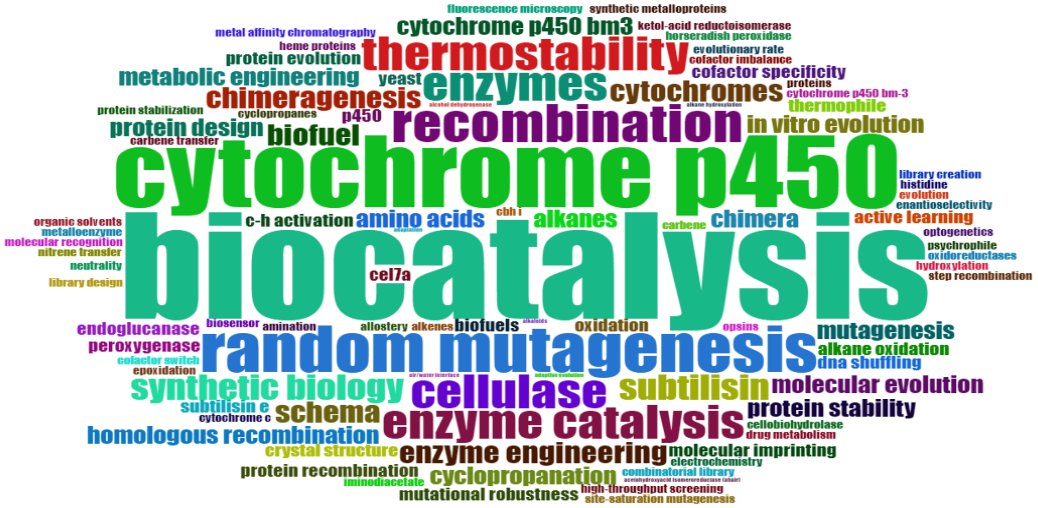

Figure-6: Frequently used keywords in publications of Arnold FH

Conclusion

From the above 9 tables, it is inferred that Arnold FH publication productivity having a constant growth with an average of 16 publications per year and 95.75 citations per document throughout her productive career; journal articles are considered a highly used channel of communication, which are distributed in various core journals in the field of chemical sciences, found the 495 authors of multi-authored documents; documents per author is 0.716 while authors per document are 1.4.It is also noticed that her 15 publications remain uncited till date. Studying the scientific career of an individual scientist will bring clarity in the authenticity of the impact on society. The innovative world has brought amazing changes in humankind from which we can find solutions for all the problems; the scientist, the scholars, are the beared the responsibility to do something better to the society and was used and esteemed by co-scientist. Arnold and his team of authors have contributed in the way to common man's understanding of 'Enzymes'. Which could help in to solve the humankind's chemical problems, and also study tried to prove that she is an outstanding performer in the field of chemical sciences and source of information for budding scientists in the field of chemistry. The study will help to budding scientists in the field and knowledge centres in the selection of appropriate sources of information.

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Conflicts of Interest

The authors declare that they have no conflict interests.

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